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# CONSTRUCTION OF ALUMINUM BRIDGE AT SZABADSZALLAS, HUNGARY

Elemer Bolcskei

The aluminum industry in Hungary was developed mainly during the second half of the 19[illegible]s, particularly through the extension of electric power lines and of the [illegible] try. It suffered heavy losses in the last years of the war and, as a consequence, the principal task after liberation consisted in rebuilding this industry. Reconstruction was accomplished within the framework of the Three Year [illegible], and the Hungarian government, recognizing the possibilities inherent in light metals, prepared plans for the development of the aluminum industry.

As a result the Ministry of Communications and Post requested the Csosur- [illegible] ate [illegible] to submit plans for a light-metal bridge at Szabadszallas. At the same time, a committee was appointed to study questions in connection with the construction of an aluminum bridge. The Aluminum Research Institute gave especially valuable assistance to the committee by carrying out experiments.

## Description of [illegible]

The bridge was built at Szabadszallas, over the principal canal of the Danube Valley [illegible] site of the old, destroyed brick bridge which had two openings with a [illegible] arch. The new bridge crosses the water course at right angles.

[illegible]re the [illegible] sta[illegible], the water-conservation authorities requested that the former middle column be dispensed with, allowing a clear opening of 12.0 meters. This [illegible], as well as extraordinarily poor soil conditions, resulted in the planning of a bridge with two supports. In view of the experimental nature of the bridge, this two-support structure appeared practical, particularly because [illegible]culation of its balancing factors presented the least problems.

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The opening of the bridge was increased to more than double the former opening. Without substantially raising the platform to a higher level, a bridge with two main supports and web plates could be constructed only by placing the main girders underneath the footwalk.

Each of the main supports consists of an I-beam fabricated from 1,050 x 8 millimeter web plates, four 100 x 100 x 13 millimeter aluminum angle beams, and boom plates assembled by means of riveting. The 740 x 6 millimeter foot-walk plate, one portion of which was taken into consideration in connection with the load capacity of the main girder, is connected by upper angle irons to the main girders.

Transverse beams were placed on the main girders every 3.15 meters. From the constructional viewpoint, the transverse beams are similar to the main girders which consist of I-beams of smaller dimensions. An auxiliary girder of similar construction was inserted lengthwise in the center of the bridge to receive the transverse beams.

Structure of Roadway

The roadway structure rests on the girder lattice formed by the main girders, transverse beams, and the longitudinal girder. It was constructed of six reinforced concrete sections and two prefabricated aluminum sections. The reinforced concrete part of the roadway structure consists of reinforced con-crete plates, 3.10 x 3.39 meters and 15 centimeters thick, prefabricated on the building site. The elements of the roadway were constructed on the banks of the river without any scaffolds and planking. Cable hoisting equipment was built to put the light-metal structure into place.

The experimental light-metal part of the roadway structure was prepared in two adjacent sections and was formed to become a member with three supports by the use of 1.05-meter wide plates. This section of the structure is essen-tially an 8-millimeter thick aluminum plate, to which six asymmetric longitu-dinal girders with Z-shaped profiles were fastened.

A comparison of the weights of two roadway structures gives the following data:

Weight of reinforced concrete roadway structure in kilograms per square meter

| | |
|---|---|
| 15-centimeter reinforced concrete plate | 360 |
| 5-centimeter asphalt | 110 |
| | 470 |

Weight of light-metal roadway structure in kilograms per square meter

| | |
|---|---|
| Light-metal structure | 57 |
| 5-centimeter asphalt | 110 |
| | 167 |

It is evident, therefore, that the weight of a light-metal roadway struc-ture is about one third that of a conventional reinforced concrete roadway structure used for similar purposes. This proves that the use of a light-metal roadway -- in spite of the excessive costs of such constructions -- is economically advantageous in wide-span bridges, where weight of the structure is a dominant factor.

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The footwalks likewise were made of light-metal, namely, 6-millimeter thick aluminum plates covered by a 2-centimeter thick asphalt layer.

Structural Material Used, Description of Manufacturing Process

For construction, aluminum-copper-magnesium alloys, the so-called dural type, were found more suitable than other alloys, mainly because of their stability.

The standard requirements (MOSZ (Hungarian State Standard), 3714) prescribe percentage limits with respect to the composition of dural-type alloys. On the basis of data obtained from the Aluminum Research Insitute, the amounts used in the alloying substances could be defined with a high degree of exactitude. Table 1 shows the respective values: the second column shows the prescribed standards, the third column, the proposed values, and the fourth column, the results of analyses of the alloys used.

Table 1

| Alloy Substance | Standard MOSZ 3714 % | Proposed Composition | Analyzed Composition |
|---|---|---|---|
| Copper | 3.5 5.0 | 4.0 | 3.92 |
| Magnesium | 0.2 1.5 | 0.6 | 0.65 |
| Manganese | 0.3 1.5 | 0.5 | 0.55 |
| Silicon | 1.0 | 0.3 | 0.23 |
| Iron | max 0.5 | 0.3 | 0.33 |
| Zinc | max 0.1 | -- | -- |

The following is a short description of the manufacture of the material. Beginning with an alloy block of suitable composition, the patterns were manufactured by stamping, and the plates by rolling. Dimensions of the stamped patterns were restricted by the weight of the presshead and the initial block. Stamping takes place depending on the composition of the material and on the shape and dimensions of the profile to be stamped, within the limits of 380-460 degrees centigrade. The plates are manufactured by the conventional rolling process employed in the manufacture of steel products, even when light-metal alloys are used. The temperature of the rolling process depends on the composition of the material and the dimensions of the plates, varying between 400 and 450 degrees centigrade.

The pieces thus produced by stamping or rolling are now placed in the heat-treating furnace. These are salt bath furnaces equipped with electric resistance heating and a temperature regulator, the margin of error being a minimum of plus or minus 5 degrees centigrade. The exact regulation of temperature is of paramount importance, because the heat-treating temperature exerts a very great effect on the ultimate strength of the finished products. The heat-treating process of the dural-type alloys is carried on between 500 and 515 degrees centigrade, depending on the composition of the alloy employed. Time used is about 60 minutes.

After the heat treating process, the pieces are cooled suddenly in water and then stored for a few days at a temperature of about 20 degrees centigrade. During this period, the dural-type alloys undergo an age-hardening process, attaining their optimum mechanical strength within 4 5 days. The profile substances and plates required for the bridge construction were manufactured from the above materials and produced by the process indicated.

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The strength characteristics of the substances are shown in Table 2, in which the second vertical column shows the data relating to the conventional, heat-treated No 36 aluminum-copper-magnesium alloy as described in Standard Specifications, MOSZ, No 3749; the third column shows the minimum strength prescribed for the specific conditions; while the fourth column shows the values actually ascertained at the time of delivery.

In announcing the specific conditions, specifications even lower than the standard were adopted. Because of the multiple-row junction of rivets, strict compliance with the regulations governing the values for elongation was considered of paramount importance. It is a well-known fact that with the increase of tensile strength, elongation will gradually diminish. It was also necessary to use greater thicknesses than conventionally required due to the structural data furnished. In addition, the perfect heat-treating process of even these substances did not appear assured. However, the results ascertained at the time of delivery revealed that such excessive caution was unwarranted.

The Aluminum Research Institute also subjected the substances to a fatigue test. According to the results of this test, fatigue occurred as follows:

1. Between fluctuations of tension from 1 to 16 kilograms per square millimeter after the stress was repeated $2 \times 10^6$ times.

2. Between fluctuations of tension from 1 to 12.5 kilograms per square millimeter after the stress was repeated $10 \times 10^6$ times.

Although these results are less favorable than those obtained in connection with similar tests made with steel structures, they are nevertheless satisfactory in view of the bridge traffic to be expected.

Table 2

| Specifications of Material | MOSZ No 3749 | Prescribed Values | Measured Values |
|---|---|---|---|
| Tensile strength (kg/sq mm) | 36 | 34 | 42 |
| Yield point (kg/sq mm) | 24 | 23 | 29 |
| Elongation (%) | 10 | 10-12 | 20 |
| Hardness (kg/sq mm)* | 100 | -- | 121 |

/*These units are not used in US practice to express hardness. The figures appear to correspond to Brinell hardness./

## Riveting

The riveting of light metals is generally done at atmospheric temperatures, in contrast with hot-riveting conventionally employed on steel structures. The disadvantage of the hot-riveting of light metals is essentially that the heat carried by the rivet softens the heat-treated basic material surrounding the rivet hole. As a result, the load capacity is considerably lessened. Light-metal rivets prepared by the cold process were used in the Szabadszallas bridge structure.

The selection of substances to be used for riveting purposes requires extraordinary care. It is known that dural type alloys have an extremely great tendency for electrolytic corrosion because of their high copper content. The danger of corrosion is also present if a light-metal alloy of a different type is selected for the basic rivet material. The most suitable procedure would be

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the employment of the [illegible] material whose composition conform[illegible] perfectly with the basic material. But this is difficult, because the basic con[illegible]struction material has a relatively high copper content, i.e., 4 percent and is not easily malleable, with the result that fashioning rivetheads from such material would require vast mechanical power. It was decided that an alloy similar to the basic material should be selected for the rivet material, but with about 2 percent less copper content.

The manufactured rivets must be subjected to the same heat-treating pro[illegible]ess as the basic material. The rivets must be inserted immediately after the refining process, because the rivet material is hardened during the gradual aging process. It is not advisable to use the rivets more than 4 hours after the heat-treating process, since a relatively great riveting power would be required and the rivetheads would not form without cracking. In the specifications it was stipulated that the shear strength of the rivets must be [illegible] kilograms per square millimeter prior to the riveting process. This specification was complied with everywhere. Fatigue tests were also carried out with riveted joints. Such tests revealed that the behavior of the joints was satisfactory.

The most difficult problem in connection with the manufacture of the bridge structure in question was the driving-in of rivets of large diameters by means of the so-called cold process. The first cold driving-in tests carried out with buttonhead rivets brought unsatisfactory results. In using this rivethead, [illegible] deformations appeared [illegible] the basic material that were visible to the naked eye. Such deformations were evident in rivethead cracks along the plane of the basic material on the one hand, and in wave-like corrugations of the rivet, on the other. These changes in shape are hazardous, especially with respect to bulges [illegible] in compressed structural elements. Therefore, this type of riveting had to be discarded.

It was ascertained that the great riveting forces and tensions exerted on the rivet spool under pressure which approximate the elastic limits, are transmitted to the mantle of the rivet hole, thereby compelling the basic material to undergo a permanent change in shape. This was substantiated by the fact that rivet [illegible] increased their original diameter by approximately 10 percent in sections [illegible] the finished rivets. For instance, the 20 millimeter rivet [illegible] about [illegible]-millimeter diameter in the section because of the change in shape.

The realization of [illegible] fact led to [illegible] ing problem. It was learned that the r[illegible]ing force [illegible] possible, and the riveting [illegible] be a few [illegible] smaller than the diameter of the riveting hole. The Aluminum Research Institute carried [illegible] experiments with differently shaped rivetheads to reduce the riveting force. The experiments revealed that if the conventional [illegible]-shaped form of the closing head were discarded and the flat or steeple rivethead were adopted, the force of riveting would be considerably lessened. Tests on a [illegible]-millimeter rivet showed that the required riveting force in tons is as follows: for buttonheads, 70-75 tons, for flatheads [illegible], and for steepleheads, [illegible].

[illegible] the flathead rivet appeared to be most suitable, from the viewpoint of the riveting force, it was nevertheless decided that the steeplehead should be adopted. The steeple-shaped design gives some lead to the head and, as a consequence, accurate riveting is more certain. Besides, the steeple-shaped head [illegible] a more standardized and, from an esthetic viewpoint, in a more attractive [illegible].

The shape of the head of light metal rivets is of no great importance with respect to the load capacity. In cold riveting, as is well-known, the rivets lack the compressive force which cooling produces in iron rivets and whereby

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[illegible] even adds to the load capacity of the joints. Tensile strength and fatigue tests carried out on joints having differently shaped rivets revealed no essential differences.

The riveting was carried out with the so-called riveting horseshoe, the maximum load capacity of which is 70-80 tons. This solved the problem of large-scale riveting, since the 16- or 20-millimeter steeple-head rivets in question could be used without any disadvantageous changes in the shape.

However, there still remained the problem of assembling the structure shipped in parts to the building site. The riveting horseshoe which weighed about 100 tons could not be shipped to this point. On the other hand the process of [illegible] riveting could not be used even in connection with the joints receiving the [illegible] stress because of the possibility of weakening the alloy material. The problem of assembling the parts locally was solved by the use of galvanized steel screws.

Basic Principles [illegible] Construction Work

Construction plans were prepared in 194[illegible]. As a consequence, the dimensions were ascertained on the basis of specifications contained in the older regulations regarding bridges.

The allowable stresses with respect to light metal structures were ascertained on the basis of the specifications of strength shown in Table 2, according to the [illegible] safety values applying to iron constructions.

According to the allowable stresses

$6 =$ [illegible] kilograms per square centimeter for tension

$6 =$ [illegible] kilograms per square centimeter for bending.

Euler's [illegible] good also in this case when dealing with very thin sections in [illegible] pressed structures. On the other hand, the limits of Euler's and Tetmajer's equations for axially loaded columns become displaced and the conversion is found at a slenderness ratio of $\lambda = 70$. In considering the foregoing, the allowable stresses for [illegible] under axial load are as follows

$$\lambda \leqq 70 \quad 6 = [illegible] - [illegible] \lambda$$

$$\lambda \geqq 70 \quad 6 = [illegible] \lambda$$

Taking [illegible]9 kilograms per square millimeter as the shear strength of rivets as a starting point, the approved [illegible] stresses were ascertained as follows (kilograms per square centimeter

For shearing $\tau =$ [illegible]

For deck plate pressure $6_p =$ [illegible]

In ascertaining the data relating to the [illegible] section of the profiles, the planner has greater latitude than in the case of iron structures. In iron structures only [illegible] profiles can be applied for which the required rolling machines are available. This restriction does not apply to light-metal structures, since the introduction of a new profile type requires only a change in the press head [illegible] and thus the expenses connected with the change are almost negligible when compared with those involved in making changes in the rolling machines.

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Since the problems of riveting have already been discussed, only the specifications relative to the spacing of the rivets, considered from the structural viewpoint, are described here. The Aluminum Research Institute compiled the following data for the allowable spacing between rivets

Table 3

| Spacing Between Rivets [in diameters of rivets] | Minimum | Suggested | Maximum |
|---|---|---|---|
| In direction of force | 2.5 | 3.0 | 4.0 |
| Vertically to direction of force | 2.5 | 3.4 | 5.0 |
| In direction of force from edge of plate | 2.0 | 2.5 | 3.0 |
| Vertically to direction of force from edge of plate | 2.0 | 2.5 | -- |
| Fastening rivets | -- | 7.0 | -- |

The equipment now available makes it possible to manufacture rivets with a maximum diameter of 20 millimeters. Due to the small allowable stress approved for shearing and deck-plate pressure, as well as the specifications calling for a maximum diameter of 20 millimeters for manufactured rivets, relatively speaking, many rivets had to be employed in the structural joints. The restriction applying to the manufactured length is likewise a hindrance to the planner, since he has to make provisions under all circumstances for one joint at every 6 7 meters.

The average modulus of elasticity of light-metal structures is 710,000 kilograms per square centimeter or about one third the modulus of elasticity for iron. This fact had to be taken into consideration in the planning with the result that the excess, manifesting itself in deflection, had to be counter-balanced by selecting large moments of inertia.

The essentially lower value of the modulus of elasticity necessitates re-evaluation of the conventional structural rules applicable to bulging and connected phenomena in iron structures. For example, the specifications relating to T-profiles -- that the length of the web plate must not be greater than 15 times the thickness employed -- have to be modified in light-metal structures.

The coefficient of heat expansion with respect to light metal structures may be assumed to be averaging $23 \times 10^{-6}$ between minus 20 and plus 40 degrees centigrade under atmospheric conditions, that is, about twice the coefficient of heat expansion for steel structures.

Protection Against Corrosion

Several types of corrosion are known to occur in light metal structures.

The first type, corrosion due to atmospheric changes, is especially dangerous to the dural-type alloys which were employed in the Szabadszallas bridge construction. The corrosion process created by atmospheric changes first attacks the copper, and, by penetrating the interior of the metal, leads to the failure of the structural members. To prevent this, all light metal structures, especially those of dural-type substances, require a protective coat of paint. Therefore, provisions were made for the use of a zinc chromate protective paint containing aluminum powder. For experimental purposes, other protective measures were also employed on the inner surfaces, not visible to the naked eye. The results are, of course, not yet available.

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The second type, electrolytic corrosion, occurs when two metals having different potentials come into contact in the presence of an electrolyte (moist air), and a galvanic cell is produced. The negative pole of this galvanic cell slowly dissolves; the voltage of the current generated -- extent of the corrosion -- increases with the oxidation-reduction potential between the two contacting metals. This phenomenon will occur even when two light metal substances of different compositions come into contact. This accounts for the fact that dural-type substances can be riveted only with dural-type rivets. In the case of light-metal structures, however, it is not an infrequent occurrence that contact must be established between the light metal and iron. Since there is an essential difference between iron and light metal, the placing of these two substances upon each other cannot be permitted; insulating material must be placed between the contacting surfaces, or the iron surface must be galvanized with a metal whose oxidation-reduction potential with respect to aluminum is relatively low. For this purpose, zinc and cadmium are suitable. Because of the excessive price of cadmium, this problem can most effectively be solved by using zinc. Zinc was applied at Szabadszallas, both with respect to the contact of steel sides and principal girders, as well as to steel screws employed for local joints.

Corrosion also affects the relationship of light metals with reinforced concrete. Due to the corroding tendency of light metals, reinforced concrete should not be placed directly on them, nor should prefabricated reinforced concrete elements be placed directly on light metals, since even the settled reinforced concrete contains chemically active compounds. The relationship between reinforced concrete and light metals is best solved by inserting an iron structure, as previous experience showed. This method was followed in the Szabadszallas bridge. The prefabricated reinforced concrete roadway elements were laid on iron plates and galvanized iron-plate supports were inserted between the rivets of the light-metal structure, underneath this iron plate.

Conclusion

The light-metal structure at Szabadszallas was manufactured from domestic raw materials exclusively, and the installation and riveting were carried out by domestic factories. The structure was manufactured in pieces suitable for shipping and was assembled at Szabadszallas, on the bank of the river.

The finished structure was constructed with the help of lifting jacks placed on the bridgeheads and by pulley blocks installed on hoists. The same equipment was used in placing the prefabricated reinforced concrete roadway. Thus, the entire superstructure was lifted into place without scaffolding and planking.

The bridge was subjected to the usual test load in December 1950, and the results conformed to the calculations. After this satisfactory test, the bridge was opened to traffic a few days later.

This bridge structure is the first of its kind in Hungary and the fourth of its kind in the world (the railroad bridge of Massena, the bascule bridge of Sunderland, and the arch bridge of Arvida) in which the entire girder construction was made of light metals. Although the weight of this structure may be estimated at about 40 percent of the weight of a similar steel bridge, the cost was 150 percent higher. Experience gained in the manufacture of this experimental bridge revealed that technical difficulties arising from the use of light-metal structures may be overcome. Such difficulties were greater in this experimental bridge, because no experts familiar with this type of work were available.

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The general application of light metal in construction is not hindered by technical difficulties. Difficulties are due to the exceedingly high costs at present. The expensive basic material accounts for the high prices initially paid. After sufficient experience has been gained, the manufacturing of light-metal bridges will not be more expensive than that of iron constructions. On the other hand, the less difficult machining and the light weight of these structures will prove to be an essential advantage.

Further experiments and research are required to find more economical ways and means for producing the alloy material of light-metal structures.

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